The Science of Sediment: Identifying Bay Sediment Science Priorities

WORKSHOP SUMMARY REPORT

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MILTON MARKS CONFERENCE CENTER

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Table of Contents

Executive Summary

As part of a long term effort to improve the region's understanding of the complex and dynamic sediment system in the Bay, the Bay Conservation and Development Commission (BCDC) hosted a workshop in October 2015 to identify regional sediment science priorities. The ultimate goal of this work was two-fold: to create a prioritized list of the most important sediment management questions for the Bay, and to develop a regional research strategy that would lay out a process for the studies and actions necessary to address these questions.

This workshop was preceded by a large body of work aimed at furthering regional sediment management, or the systems approach of deliberately managing sediment in a way that maximizes both natural and economic efficiencies to improve sustainable water resource projects, environments, and communities.[1] This work includes a 2010 Sediment Science Workshop co-hosted by BCDC and the United States Geological Survey (USGS) that identified current data gaps and modeling efforts; an extensive literature review of sediment research, notably of the 2013 Marine Geology Special Issue; and a Sand Mining Science Panel hosted by BCDC in 2014, among others. The 2015 Science of Sediment Workshop[2] hosted by BCDC, with assistance from the San Francisco Sentinel Site Cooperative (SFSSC), was an overall effort to help align the multitude of scientific and research pursuits in the region with the present and future needs of managers.

One of the primary objectives of this sediment strategy workshop was to gain consensus between scientists, academics, and practitioners dealing with sediment on a daily basis about what information is needed as a region, and how decisions should be made. In order to attain this goal, a comprehensive list of participants was invited, including a range of sectors (government, research, consulting, management, regulation) and across a breadth of expertise (hydrology, geomorphology, flood control, wetland management, dredging, sediment transport, etc.). In the end, approximately 40 people were able to attend the first day of the workshop and generated a list of regional priority sediment questions.

In order to facilitate the discussion of such a complex and amorphous concept as regional sediment management, the workshop was organized around four geographic areas and uses of sediment in the Bay. These four categories, or sectors, were: Watersheds, Tributaries, and Flood Control Channels; Marshes and Mudflats; Beaches and Non-wetland Shorelines; and Open Bay and Subtidal Areas. The top questions for the region in each of these areas were generated and prioritized. Table 1 shows the highest priority questions identified for each category, as identified during the workshop.

[1] US Army Corps of Engineers. Regional Sediment Management (RSM). Retrieved from http://rsm.usace.army.mil/

[2] Also referred to as the sediment strategy workshop in this summary

Watersheds, Tributaries, and Flood Control Channels	How can we design channels to help convey sediment to marshes and baylands rather than into the Bay?
Marshes and Mudflats	How can we verify or test (i.e., through pilot study) the modeling results of in-Bay placement naturally redistributing to marsh plains, leading to more efficient beneficial reuse?
Beaches and Non-wetland Shorelines	Are there particular shoreline areas that are most at risk from erosion and sea level rise (SLR)?
Open Bay and Subtidal Areas	Does placement of dredged sediment at in-Bay disposal sites benefit shores and wetlands?

Table 1 Management questions identified across four geographic areas of sediment activity that were voted as being of highest priority to participants during the workshop

This workshop is not a completed process insofar as a research strategy for the region is yet to be completed. However, this workshop provided many of the building blocks that need to be pieced together, including an extensive list of prioritized management questions (Appendix B), details of the discussions that took place, and outlines from each research strategy group that began identifying current research, potential pilot studies, and necessary data and monitoring updates (in this summary report). Furthermore, the workshop received positive feedback, and several participants expressed interest in continuing work towards developing the comprehensive research strategy for the region.

Ultimately, through this workshop and the synthesis of management questions herein, the importance of furthering sediment science and research in the region was confirmed, as it will allow us to accomplish four overall objectives. These four takeaways sum up the extensive list of management questions generated, and correspond with the research discussions that took place. They are to:

- Understand how much of what type of sediment we have, and where;
- Increase fluvial and tidal connections to improve sediment conveyance;
- Increase the beneficial reuse of sediment in the context of a limited incoming supply in order to maintain wetlands;
- Identify shorelines at risk from sea level rise and ways to reinforce them through sustainable means, mimicking natural systems.

These objectives can be met with the guidance of a regional research strategy. This summary report provides a discussion of the ideas generated at the workshop towards this end. It is proposed that three working groups continue the development of this strategy over the coming year.

Introduction

The Bay Conservation and Development Commission's Sediment Management Team, with guidance from the US Geological Survey (USGS) and the San Francisco Estuary Institute (SFEI) and assistance from the NOAA San Francisco Bay and Outer Coast Sentinel Site Cooperative (Sentinel Cooperative), hosted a two-day workshop during October 2015 to identify priority management research needs around physical processes of sediment in the Bay Area, and to begin brainstorming the formulation of a prioritized scientific research strategy for the Bay. The workshop took place on October 13th and 14th, with 37 participants on the first day, and 22 participants on the second day, representing the science, management, regulatory, consulting, and non-profit sectors and including expertise spanning sediment transport, hydrology, geomorphology, wetland management, shoreline management, dredging management, and coastal engineering, among others.

The first day lead to the development of an extensive list of brainstormed sediment-related questions faced by managers across a range of geographic areas including: (1) watersheds, tributaries, and flood control channels that drain into the Bay; (2) surrounding marshes and mudflats; (3) beaches and non-wetland shorelines around the Bay; and (4) the open water and subtidal areas of the Bay. Participants voted on their top four, priority management questions from each of these geographical groups, targeting the top sediment knowledge gaps for scientists and managers in the Bay area.

The second day of the workshop included a subset of the participants on the first day, with a greater portion of representation from scientists who conduct research on sediment in the Bay. This was part of the workshop design. The goal of the second day was to discuss a strategy for prioritizing future research that would address the high-priority management needs for the region. Due to the nature of sediment currently being managed in a project-by-project, agency-by-agency, multi-jurisdictional fashion, the objective was to identify overlapping monitoring and data that could benefit the region as a whole, and address multiple questions. Through follow-up with several participants, the Sediment Management Team will continue to grow these discussions into a science strategy that institutions use when prioritizing research or applying for funding for projects with a regional sediment interest.

This document provides a summary of the evolution of this workshop, the main outcomes from each component, and further detail covering the discussions that took place. This is by no means an end to the conversation, but rather a starting point that is intended to be furthered in the coming months and years and help guide the research of studies addressing sediment questions in the Bay.

Workshop Evolution

This sediment strategy workshop was preceded by several sediment-science related workshops, science panels, and literature reviews. These activities were conducted by BCDC, often in conjunction with others such as the US Geological Survey (USGS), the US Army Corps of

Engineers (USACE), and San Francisco Bay Regional Water Quality Control Board (Water Board) and others to better understand the current approach of scientists and managers dealing with regional sediment management issues in the San Francisco Bay.

Most notably, in 2010, BCDC and USGS co-hosted a State of Sediment Science workshop attended by scientists and managers. This workshop resulted in identifying top data needs to further research and modeling efforts for the Bay and watershed, and garnered support from the research community for continued investigation of sediment management issues.

In 2011, BCDC received a Coastal Impact Assistance Plan (CIAP) grant to prepare an integrated, regional sediment management strategy for studying, understanding and managing sediment processes in the Bay. As part of the CIAP work plan, BCDC responded to the need for research and the on-going data gaps faced by shoreline and sediment managers by collecting and cataloguing data and research papers and reviewing literature related to the development of a regional sediment management plan and research strategy. Grant related tasks have been ongoing and continue to work toward an increased understanding of sediment transport, sediment sources and sinks, and a sediment budget for the Bay.

In 2014, to better inform the sand mining permitting process, BCDC organized a day long Sand Mining Science Panel to discuss the current knowledge of the Bay's bathymetry, sediment transport, and subtidal habitats in relation to the areas of sand deposits in the Bay. The ensuing panel discussion highlighted the current scientific knowledge and recently published findings on sediment transport and provided topics of interest to be addressed by technical working groups and committees. Through their participation in these events, the scientist, consultants, and managers discussed current work and research efforts, and further identified data gaps and the need for additional research about San Francisco Bay sediment management and physical processes.

It became apparent that the demand for information was great, but also that no strategy was in place to organize and prioritize management questions that could guide scientists in their selection of sediment related research topics, which in turn would inform managers with current, applicable science. With this in mind and with the preceding workshops and panel as a starting point, the BCDC Sediment Management Team began planning this 2015 sediment strategy workshop.

To begin discussing top priority management needs and defining a science strategy for the region, in March 2015, BCDC contacted scientists and researchers with sediment and physical process and/or modeling expertise to gauge the level of interest and availability of participants in the workshop. The response was positive, and as planning commenced, several of these scientists helped BCDC refine the scope and purpose of the two-day strategy workshop.

During this time, the BCDC sediment team met with the USGS and the San Francisco Estuary Institute (SFEI) to discuss workshop structure, and worked internally and with the Sentinel Cooperative to discuss the growing list of management questions and how to best organize them for a productive discussion. To further understand and refine these questions, the team met with partner organizations involved in sediment including flood control agencies and members of the Long Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region (LTMS). At these meetings BCDC discussed the goals and mission behind the strategy workshop, and asked about the types of monitoring and research that would be helpful to the groups. BCDC asked for feedback in narrowing the list of management questions that would be the focus of the two-day workshop.

During the planning phase it became apparent that prioritizing the list of management questions was challenging; it was difficult to group them as many related to several overlapping and intertwined topics of interest. When the invitations for the October meeting were sent out in September, a table of internally developed management questions was included for managers of different sectors. This group of managers was asked to review and rate the questions by level of importance and add any missing questions. The goal of this work was to inform participants about workshop topics, provide an opportunity to advance priorities, and to develop a targeted list of relevant questions to present to the workshop participants. The feedback revealed how challenging it was to eliminate questions from the list, as they all seemed relevant and important. The primary feedback received was for clarification and addition of priorities that were not included. A complete list of these questions and rating responses can be found in Appendix A.

Workshop Overview

Overall Workshop Goal

To establish a regionally relevant prioritized physical science research strategy for San Francisco Bay.

There were three primary objectives for the workshop. Objectives 1 and 2 were accomplished before and during the workshop, and objective 3 was initiated and is currently a work in progress.

1. Establish an understanding between managers and scientists about information needs and management decision considerations.
2. Identify priority management issues by sector related to the physical processes of sediment in the Bay.
3. Develop a research strategy for how to address the highest priority sediment management issues.

DAY 1 – MANAGEMENT DRIVEN DISCUSSION

Objectives

- Brainstorm and develop a list of refined management questions within four geographic sectors dealing with sediment management in some capacity (watersheds, tributaries, and flood control channels; marshes and mudflats; beaches and non-wetland shorelines; open bay and subtidal areas).
- Clarify management questions, group related questions, and begin to identify questions containing elements that may link across sectors.
- Determine which management questions are of highest priority to the group, to be used as the foundation for targeting research aimed at addressing sediment needs for the region.

Attendees

Workshop participants included representatives from regulatory and resource agencies, flood protection, dredging, watersheds, habitat restoration, consultants, and researchers within the sediment sciences (See Appendix B for a complete list of participant names and agencies).

Summary of Management Presentations

To set the stage for the brainstorming sessions, four stakeholders representing flood protection, dredging, habitat restoration, and beach and shoreline management provided an overview of their work related to sediment, how they use science in their decision making, and the biggest challenges they face involving current sediment management actions.

Carl Morrison, President, Bay Area Flood Protection Agencies Association

Flood Control

Currently, sediment in the flood protection system is difficult to manage because it builds up in channels and decreases flood capacity. The Bay area flood management system is trying to move away from concrete channels and towards multi-benefit habitat projects, however, there are many challenges including:

- Cost. Cost is a challenge in that once a project qualifies as habitat, permits are required to remove any sediment. Furthermore, flood protection agencies do not have an exemption from water and wastewater policies. Concrete channels are decaying, and these organizations do not have funding to improve infrastructure.
- Perception. The perception of the flood protection agencies is that they are "developers," and they are treated as such as part of environmental regulation. However, their charge is to protect people and maintain capacity for when there is a flood.

- Contamination. Flood protection agencies remove sediment that reduces capacity of the flood protection system. They would prefer to use sediment from channels to restore wetlands. However, much of the sediment has naturally occurring contaminants that require it to go to upland landfills. A solution might be to place sediment somewhere it can be managed in a way that metals are contained.
- Location. There is a need to identify location where sediment can be reused beneficially. There are opportunities to study places where sediment could be used to supplement wetlands.

Mike Vasey, Director, San Francisco National Estuarine Research Reserve (SF Bay NERR)

Marshes & Mudflats

The NERR works with partners towards the goal of preserving marsh landscapes. These marshes offer a "reference" for what tidal wetlands looked like in the past. However, these mature tidal wetlands are at risk due to sea level rise (SLR). Marshes are at a higher risk from SLR, decreased sediment deposition and marsh accretion.

- Interactions with SLR, sediment supply, and marsh accretion need to be addressed simultaneously, as these combined processes are required for wetland sustainability.
- The supply of sediments and ability for marshes to migrate is key for determining their long term condition and changes.
- The SF Bay NERR has been studying marshes across the US and now has "Sentinel Sites" that can be used to provide early detection of marsh deterioration, including declines in species and processes, and indication of the effects of SLR on the larger system. The intention is to understand what's happening in mature marshes to better inform restoration projects elsewhere.
- By 2100 Bay Area marshes are expected to turn into low-elevation mudflats. Working with the Sentinel Cooperative, we have observed rates of accretion in marshes responding to SLR, sediment supply, and salinity.
- We want to regionalize a sentinel site-like program in SFB, to understand the ability of marshes to migrate over time. Sediment is a critical issue with respect to this early warning program in the Bay.

Kristin Ward, Wetland Ecologist, NPS Golden Gate National Recreation Area (GGNRA)

Beaches & Shorelines

- GGNRA owns and manages 80,000 acres of property in 3 counties and includes the Crissy Field shoreline.
- The National Parks Service (NPS) at Crissy Field is directed by management policy guidelines regarding how to manage geologic resources. One management guideline calls for the allowance of natural geological processes to proceed without intervention.
- Most questions/challenges are related to beaches such as Crissy Field either having too much and too little sand. For example, the inlet at Crissy Field does not function naturally,

filling with sediment and closing, preventing public access, so that it must be mechanically maintained (an exception to the guidelines). This human intervention to the system has lead to a philosophical debate about whether to manage the inlet artificially to allow for recreation, or allow for natural processes and manage it as a tidal marsh.

- Currently, the inlet is managed through mechanical breaches twice a year. GGNRA engages with the scientific and engineering community (including PWA, USGS, others) to understand the marsh, sediment quality, and biological impacts of the system and their management interventions.
- Other sediment management issues include erosion at the beach down shore from the marsh (from West to East), beginning with marsh creation. When the marsh was created, it acted as a sediment sink and captured the sediment that would have been normally supplied to the beach. This greatly affected recreational visitors by impacting the sand near the promenade and collecting debris. This led to the NPS intervening with beach nourishment activities to benefit public access and recreation, and bury debris that was a problem for beach users.
- On the other end of Crissy Field, the NPS has had problems with sand accretion near the Golden Gate Bridge. It is creating a landmass that plugs the storm drain outfall near the Presidio. However, cleaning it out affected overwintering snowy plovers in the area. To resolve the issue, a longer outfall pipe was installed to avoid sand impoundment in the storm drain and reduce disturbance to plovers.
- The NPS doesn't have expertise in-house to deal with how to assess sediment transport; there is no good funding source to deal with projects involving sediment. However, the NPS remains interested in sediment supply in the Bay and how their management activities interact and affect the outer coast.

Brian Ross, Dredging & Sediment Management Team, US Environmental Protection Agency (EPA) Region 9

Open Bay & Subtidal

- The EPA management sediment issues including: water quality, sediment quality, and toxicity. EPA Region 9 works with the Water Board and SFEI, and is responsible for dredged sediment management in the Bay in accordance with the LTMS Program.
- The majority of staff time is spent on individual dredging projects, although some is spent monitoring in tidal wetlands. Planning is a smaller component of EPA's work.
- The USACE has policies (the federal standard) that will not allow it to spend additional money for beneficial reuse of maintenance dredged sediment beyond the least cost alternative. This policy that needs to be addressed in order to allow us to keep sediment in the system.

- The cost of beneficial reuse is generally more expensive due to handling and transportation (distance). Since a barge can more easily bottom dump offshore than double-handle sediment to put it on beaches or wetlands, the cost is typically less.

Development of Priority Management Questions

Brainstorming Sessions

During the workshop's brainstorming session, an extensive list of over 150 management and science questions was generated from four groups. Groups were predetermined, with the intent of creating a balance between scientists and managers, as well as mixing expertise across all four geographic and management sectors. Each group went through four rotations so that each participant ultimately contributed to the final list of questions for each geographic region (Watersheds & Tributaries; Marshes and Mudflats; Beaches and Other Shorelines; and Open Water and Subtidal Shoals). This structure was an effort to overcome the local place-based management thinking we are traditionally accustomed to, and begin gaining a broader understanding of inter-related, regionally significant issues.

Despite the extensive list of questions, most can be distilled down to the following broad management questions:

- How much coarse and fine-grained sediment do we have, and what are the implications of how we "use it" now?
- Where is sediment needed, and how do we best move it there?
- How are we going to adapt to changes over time, especially sea level rise?

Additionally, each group developed their own classification system for their group's questions, based around general themes or logical categories they identified across questions. The individual small group themes identified were:

<u>Watersheds, Tributaries, and Flood Control Channels</u>

- Sediment conveyance
- Sediment supply
- Sediment (sediment storage, texture, and grain size)
- Sediment fate (both current and future fate and transport)

<u>Marshes and Mudflats</u>

- Processes influencing resilience to sea level rise
- Strategies for promoting resilience to sea level rise
- Ecosystem linkages (across a continuum of habitats) and conservation trade-offs
- Knowledge base to support resilience (sentinel sites and regional monitoring)

This group also identified three areas in which managers can influence outcomes, by which questions could be further classified. They noted that all the marsh and mudflat questions were either research-based, related to management needs, or referencing criteria necessary for prioritization.

Management areas that can affect outcomes:

- Accretion/sediment supply modification
- Timing, placement, and restoration approach
- Lateral migration of sediment within the Bay

Beaches and Non-Wetland Shorelines

- Where?
- Why?
- How?
- When?

This group also noted that questions about shoreline type and variation were reoccurring. This may be indicative of a lack of complete understanding of Bay shoreline types and features.

Open Bay and Subtidal Areas

- Existing conditions (load and grain size)
- Future changes (sea level rise and water resource management)
- Management Implications (anthropogenic change, engineering modification, management decisions, and human interventions that affect the Bay)

Group Discussion

Once the small group brainstorm was complete, the participants returned to a participant-wide discussion. During this discussion, participants responded to the collection of management questions raised throughout the rotations, and identified several overarching questions and comments, such as:

- Can we define tipping points and appropriate thresholds?
- The multiple temporal and spatial scales acting simultaneously create a challenge (e.g. disproportionate rates of change and impact from sea level rise, diminishing sediment supply).
- Time scales of adaptation (for processes, ecosystems, and humans)
- Geologic time scale
- Geographic spatial scales

- Many of the questions listed contain value judgments, and may not be able to be answered merely through the examination of physical science principles. Rather, their answers may depend on which stakeholder's criteria or value system is being used to set priorities.

Below is an example of a set of prioritized management questions and a corresponding research framework that the group developed through discussion:

- How can we design an integrated monitoring program (i.e. water levels, accretion rates, sediment supply) of both natural and restored marshes to aid in future restoration designs? Can we use the data-driven transfer of lessons learned from existing restoration projects to aid in improving designs for newly planned restoration efforts? (M4)[3]
- What factors are needed to identify optimal locations for marsh restoration? Are there remote sensing approaches? (M10)
- Do we have enough natural marsh sentinel site locations to project the future of marsh resiliency (long term change over time)? (M27)

From these questions the group developed a corresponding research and monitoring framework as an example of how a strategy could be designed:

- Develop a program for monitoring natural and restored marsh sites.
- Include monitoring of water levels inside a restored site to determine if excavation or other management interventions are necessary for designing other restoration projects.
- Create a standardized approach for developing a monitoring program so the community can learn from it.
- Related known ongoing efforts:
- USGS has been working on a project that measures rates of contaminant bioaccumulation in the marsh, and then scales it up with remote sensing. The USGS uses a hydrolab application to estimate the sediment concentration in channels and calibrate satellite information with sensitivity analyses.

Prioritizing Management Questions

After the group discussion, participants were asked to select four priority questions from each geographic/management area. Below are the selected top four/five priority management questions that arose from the brainstorming rotations, the subsequent larger group discussion and a prioritization exercise. A comprehensive list of all questions can be found in Appendix C.

[3] This is the question I.D. that can be used to locate each question in the comprehensive list found in the appendix.

Q I.D.	Votes	Watershed, Tributaries, and Flood Control Questions	Small Group Theme
W1	18	How can we design channels to help convey sediment to marshes/baylands rather than into the Bay?	Conveyance
W2	15	What do we estimate to be the change in sediment supply/erosion of our watersheds into the future (using modeling)?	Supply & Fate
W3	13	Where can we reuse dredged sedimentfrom channels—nearby, locally, and cheaply?	Fate
W4	13	How do we resolve the conflict between policies encouraging the trapping of sediment upstream and those allowing it to flow through? -Are there opportunities here for decision science tools? -Can we identify the hurdles? -Could we use multi-criteria decision analyses tools to address sediment management alternatives?	Supply
W5	13	How do we better link our flood plains with our marsh plains?	Fate
**Since there was a tie, the top 5 questions were included for this sector*			

Q I.D.	Votes	Marshes and Mudflats Questions	Small Group Theme
M1	18	How can we verify or test (i.e., through pilot study) the modeling results of in-Bay placement naturally redistributing to marsh plain, leading to more efficient “beneficial reuse”?	
M2	13	How and where do/should we assist vertical accretion of marsh/mudflats? (a) Viability of thin layer deposition of dredged sediment in marshes; (b) reconnecting flood control channels to marshes; (C) effectiveness/timing/ location of sediment placement (source replenishment) on mudflats for redistribution onto marshes; (d) criteria to prioritize locations for marsh conservation or restoration	
M3	12	What is the predicted “new normal” for suspended sediment concentrations (a critical driver for predicting marsh accretion rates), and how does it vary spatially around the Bay.	
M4	12	How can we design an integrated monitoring program (i.e. water levels, accretion rates, sediment supply) of both natural and restored marshes to aid in future restoration designs? Can we use the data-driven transfer of lessons learned from existing restoration projects to aid in improving designs for newly planned restoration efforts?	

Q I.D.	Votes	Beaches and Non-wetland Shoreline Questions	Small Group Theme
B1	11	Are there particular shoreline areas that are most at risk from erosion and sea level rise (SLR)?	Where
B2	11	Are there new/candidate sites for shoreline restoration where natural processes can be used, as opposed to retrofitting existing armored shorelines (i.e. using horizontal levees)	Where
B3	11	Where should managed retreat be applied/implemented? What are the cost/benefits?	Where
B4	9	Where is armoring or infrastructure no longer needed and can be removed to restore sediment supply/ transport?	Where

Q I.D.	Votes	Open Bay and Subtidal Areas Questions	Small Group Theme
S1	18	Does placement of dredged sediment at in-Bay disposal sites help with shores and wetlands?	Management Implications
S2	14	Can we develop sediment budgets for embayments, tributaries, and the flux between the Golden Gate (GG) and outer coast?	Existing Conditions
S3	13	What is the sand budget of the Bay? (Including watersheds, shorelines, beaches & GG) What is the source and transport of sand moving on and off of Bay beaches?	Management Implications
S4	12	How would deeper water (due to sea level rise) affect sediment deposition dynamics of mudflats and shallow subtidal shoals?	Future Conditions

DAY 2 – SCIENCE DRIVEN DISCUSSION

Objectives

- Reorganize the top priority management questions from the four geographic sectors from Day 1 into groups that lend themselves to be addressed through research questions and studies.
- Brainstorm and develop the important components of a research strategy for each new set of management questions, considering current, possible, and future research ideas, in addition to timing, phasing, and possible ways to synthesize findings so they are useful to managers.
- Identify overlapping study ideas between the groups such as region-wide monitoring or data needs that are relevant to multiple studies and management questions.

Attendees

A list of participants attending the second day of the workshop can be found in Appendix B.

Developing a Research Strategy

Management Question Review and Reorganization Discussion

The goal for the morning was to decide the best approach for addressing the high priority management questions arising from Day 1. The workshop team felt that because so many of the management questions from Day 1 were related, or were variations of a single issue, it was important that the research group on Day 2 be able to see a longer list of questions that received votes. Thus, the top four management questions from each sector of Day 1 were presented to the predominately science-based group on Day 2, along with handouts of the next five highest-voted questions. The group was to devise a research strategy that would encapsulate questions across geographic sectors, identifying common monitoring needs or model inputs that could inform studies on both a local and site-specific, but also regional and cross-sector scale.

In an effort to reorganize the management questions in a way that would facilitate their adaptation to research studies, the group brainstormed several organizational structures that could be used to regroup the top management questions based around scientific pursuit. Suggested structures were:

<u>Structure 1</u> – Categorize questions by:

- Sea level rise – near and long term
- Sand
- Mud, transport pathways, and marsh accretion

<u>Structure 2</u> - Categorize questions by:

- Sediment budget
- Hydrology/geomorphology design and physical conditions
- Biological and ecosystem services
- People and Infrastructure
- Monitoring to inform modeling (especially to address sea level rise)
- Research gaps

*This structure includes biology, which was beyond the scope of this workshop.

<u>Structure 3</u> – Categorize questions by:

- Fate of sediment – from where we don't want it to where we want it
- Sediment deposition, budget, and supply
- Status – current and future

<u>Structure 4</u> – Categorize questions by:

- How much sediment do we have?
- Where is the sediment we have?
- Where do we need sediment?
- How will we get sediment to where it's needed, and how much will it cost?
- What are the impacts and trade-offs of management actions?

During the brainstorming of the above organizational structures, full group discussion ensued that covering the following points:

- Jeffery Steevens from the US Army Corps of Engineers Engineer Research (ERDC) and Development Center proposed holding another workshop dedicated to addressing the management questions that could be answered through social science and decision science tools, such as, "where do we need sediment?" as the scope of this workshop was specifically focused on physical sediment processes.
- There was general consensus that modeling and sea level rise should not be segregated into separate categories, but rather should be elements threaded throughout each of the sectors.
- Other important discussions that occurred during this session revolved around whether or not all of the questions at hand were in fact management questions, or how answering them would help improve managers' ability to make decisions.
- Examples of direct <u>management linkages</u> from questions relating to suspended sediment or sand budget questions were discussed, such as:
    - Understanding of suspended sediment concentrations could inform the permitting of a restoration project
    - Understanding changes in a local sediment budget could inform decisions about the handling of dredged material
- As an example, even though a sediment budget may be possible to develop across a range of high to low fidelity and scales, depending on the management need, it is important to ask whether it is worth the investment from a management perspective. In other words, is the value of information that would be gained through development of a robust, fine-scale sediment budget worth the cost, given the amount of support it would provide to managers on a regional basis?
- Ultimately, consensus emerged around the importance of maintaining a clear link between the management questions and needs and the proposed research questions.

Challenges identified associated with the development of a robust sediment budget (or other rigorous study) were:

- Is it possible to get a sand budget with <u>error bars small enough to inform management questions</u> regarding mining?
- Sediment budgets are scientifically intensive, especially with sea level rise uncertainties, and components must add up.

Other questions that were discussed regarding how to proceed with developing research studies were:

- Managers must make decisions on a shorter-term basis than science may be available. Therefore, studies that can be addressed in the near term (2-3 years) are most valuable in order to adjust management practices in a timely, incremental manner. However, longer-term monitoring is also critical for building datasets that can inform future decision-making.

- Are we thinking too narrowly by isolating ourselves to geological sciences? Should we broaden our thinking to include social and decision science?

Reorganizing the Priority Management Questions into Scientific Process Groupings

After discussion and review of the top priority management questions from the first day, the Day 2 group decided to reorganize the questions based on their relevancy to: *(1) sediment fate and transport; (2) sediment budget and supply; and (3) sediment status, risk, and resiliency* (most closely resembling Structure 3 above). Cost and temporal scales were also discussed as important components to be considered to maintain realism in study design. It was also noted that engineering interventions or other adaptive management strategies could be considered under the *Fate* category, but pilot studies might be best considered independently.

The top management questions were thus reorganized by consensus as indicated in the following section. Each breakout group had its own team of self-selected scientists and/or managers of relevant expertise working towards a strategy to address their group's questions.

Breakout Strategy Groups

The workshop team organizing team believes that it was important to allow participants to self select which topic of research strategies they wanted to contribute to. Worksheets were provided to each group to assist their discussion, in an effort to guide the conversation and create some consistency between the groups (Appendix D). However, due to the free-form nature of the conversation, the outcome of each group's session resulted in a unique format. Additional notes from each group's discussion can be found in Appendix E.

Fate and Transport

Group Members

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Q I.D.	Votes	Management Questions to Address
M2	13	How and where do/should we assist vertical accretion of marsh/mudflats? (a) Viability of thin layer deposition of dredged sediment in marshes; (b) reconnecting flood control channels to marshes; (C) effectiveness/timing/ location of sediment placement (source replenishment) on mudflats for redistribution onto marshes; (d) criteria to prioritize locations for marsh conservation or restoration
S1	18	Does the placement of dredged sediment at in-Bay disposal sites help with shores and wetlands?
M1	18	How can we verify or test (i.e., through pilot study) the modeling results of in-Bay placement naturally redistributing to marsh plain, leading to more efficient “beneficial reuse”?
M5	10	What is the best percentage of sediment that we can get to naturally redistribute from in-bay placement to the mudflat/marsh plain, and what percentage of successful redistribution is necessary to be considered “beneficial”?
W1	18	How can we design channels to help convey sediment to marshes/baylands rather than into the Bay?
M3	12	What is the predicted “new normal” for suspended sediment concentrations (a critical driver for predicting marsh accretion rates), and how does it vary spatially and temporally around the Bay? (Necessary input for marsh models)
M4	12	How can we design an integrated monitoring program (i.e. water levels, accretion rates, sediment supply) of both natural and restored marshes to aid in future restoration designs? Can we use the data-driven transfer of lessons learned from existing restoration projects to aid in improving designs for newly planned restoration efforts?

Working Group Process

The *Fate and Transport* group organized their set of prioritized management questions in a way that focused on the ‘how’ and ‘where’ of question M2, related to assisting the vertical accretion of marshes and mudflats. The group recast the prioritized management questions based on the source of sediment feeding marshes and mudflats—either from fluvial sources in the watershed, or redistributed Bay sediment. In light of time constraints, the group focused on a discussion of uncertainties related to in-bay redistribution and the kind of information that would be necessary to address efficacy of in-bay dredged sediment disposal for promoting marsh/mudflat accretion. However, the group emphasized that the focus of this discussion should not diminish the importance of the other questions brought to the group, and that follow-up work to this workshop could address some of the other fate and transport questions, such as how to redesign channels to help convey sediment to marshes and mudflats.

Key Issues

The fluvial contribution and the dynamics of sediment movement at the tidal-fluvial interface were highlighted as the biggest sources of uncertainty in sediment transport models, both conceptually and numerically. Because of its dynamism, the tidal-fluvial interface is a difficult physical location to study, requiring longer-term monitoring (perhaps at a pilot location to start). This presents a significant challenge to planning for environmental changes resulting from upstream land-use practices or climate change (i.e., projecting how dynamics in the tidal-fluvial interface are likely to change with head of tide shifts resulting from combined changes in precipitation/runoff and sea level rise).

Reorganization of Prioritized Management Questions

The group further reorganized the Management questions as follows:

How and where do/should we assist vertical accretion of marsh/mudflats? (a) Viability of thin layer deposition of dredged sediment in marshes; (b) reconnecting flood control channels to marshes; (c) effectiveness/timing/location of sediment placement (source replenishment) on mudflats for redistribution onto marshes; (d) criteria to prioritize locations for marsh conservation or restoration (M2); (e) design of an integrated monitoring program (i.e. water levels, accretion rates, sediment supply) of both natural and restored marshes to aid in future restoration designs (M4).

<u>Sediment Coming From In-Bay Redistribution</u>

a. Does the placement of dredged sediment at in-Bay disposal sites help with shores and wetlands? (S1)
b. How can we verify or test (i.e., through pilot study) the modeling results of in-Bay placement naturally redistributing to marsh plain, leading to more efficient “beneficial reuse”? (M1)
    i. What is the best % of sediment that we can get to naturally redistribute from in-bay placement to the mudflat/marsh plain, and what % of successful redistribution is necessary to be considered “beneficial”? (M5)

<u>Sediment Coming From Fluvial Sources</u>

c. How can we design channels to help convey sediment to marshes/baylands rather than into the Bay? (W1)
d. What is the predicted “new normal” for suspended sediment concentrations (a critical driver for predicting marsh accretion rates), and how does it vary spatially and temporally around the Bay? (M3)
e. How can we design channels to help convey sediment to marshes/baylands rather than into the Bay? (W1)

In-bay Redistribution Uncertainties

The group also focused on a discussion of key uncertainties related to in-bay redistribution and the kind of information that would be necessary to address efficacy of in-bay dredged sediment disposal for promoting marsh/mudflat accretion. The biggest sources of uncertainty in models projecting the fate and transport of in-bay disposal, both conceptually and numerically, were:

1. Initial conditions for modeling the fate/transport of in-bay placed material:
    a. What portion of sediment stays suspended and what portion settles on the bed?
        i. Could this be answered with high-density grids? What would be the cost?

   b. What are the erosion and deposition characteristics [in marshes], and what are the rates?
      i. What is the rate of bank failure?
      ii. What is the rate of consolidation?
   c. What is the shear stress (force of water on the bed)?
      i. Determines when the sediment will vertically re-suspend.
      ii. Challenge: Hard to define
2. Efficacy of different methods of sediment placement
   a. E.g., Slurry sediment from a scow to distribute more evenly and keep more in suspension (reduce amount that settles immediately)
3. Temporal variability and time scales
   a. Best time of year and time of day for placement (seasonality of wave climate and daily tidal cycles)
   b. Long term monitoring (2-5 years) is needed to feed the model
4. Spatial variability of ambient or boundary conditions (i.e., results of in-bay placement will differ in different regions around the Bay)
   a. What are the horizontal fluxes (i.e., deep channel to shoals to mudflats to channels etc.)?
   b. What portion of mudflats and marshes do Bay suspended sediments versus fluvial suspended sediments feed, and where are they?
   c. Is there a river inflow? How much flow? How much sediment does it carry (e.g., land use practices of upper watersheds affects sediment supply into the estuary)?
   d. Is it a wet year or a dry year?

Data Needs and Suggested Pilot Studies

Models are only as good as the underlying topographic data. A basic data need that would contribute to multiple studies would be bathymetry and/or lidar in the intertidal zone and marsh plain (this requires high accuracy lidar during the lowest tides of the year to see all mudflats and shoals). These data need to be collected periodically to monitor change and understand sediment fluxes. Lidar studies from 2005 and 2010 (NOAA, FEMA, USGS) try to address this, but lack accurate bathymetry. Lidar from 2012 and 2014 was not collected during the lowest tide. It may be worth exploring other remote-sensing options as a more cost-effective monitoring tool over the long-term. The group did note that better data exists south of the Dumbarton Bridge, making it a good location to consider developing pilot projects if project selection criteria were based on good bathymetric data sets.

Another priority need is to identify locations of marshes with likely fluvial influence, as a way to prioritize locations for pilot studies. Pilot studies will play out very differently in different parts of the Bay. We need to understand the spatially explicit ambient conditions prior to conducting a pilot study as a way of anticipating how results might differ in different locations. This might require long term monitoring in pilot locations identified as having both fluvial and tidal influence.

Several ideas were generated for potential pilot studies that might resolve uncertainties in in-bay redistribution and efficacy of in-bay disposal:

1. Build off of existing pilot studies and ongoing related efforts:
    a. San Pablo Bay
    b. Corte Madera
    c. South Bay—the restored salt ponds have had significant accretion of sediment, but the source of this sediment is unclear (i.e., is it coming from in-bay or from erosion of neighboring mudflats, which would be a more negative trade-off). There is some existing modeling projecting the fate of in-bay placement of dredged sediment already, and it could be verified and improved with a pilot-scale test where sediment fluxes before and after in-bay placement are measured.
        i. As part of the LTMS Program, there is a study underway to develop a framework and study design to better understand the ability to strategically place dredged sediment in areas that would allow the natural physical processes to move sediment on to marshes or restoration sites.
2. Compare pathways of sediment supply and export between:
    a. Mature/vegetated marshes
    b. Newly restored marshes

Sediment Budget and Supply

Group Members

Mark Johnsson (CCC), Doug George (Applied Marine Science), Lester McKee (SFEI), Jeff Steevens (USACE - ERDC), Maureen Downing-Kunz (USGS)

Q I.D.	Votes	Management Questions to Address
S2	14	Can we develop sediment budgets for embayments, tributaries, and the flux between the Golden Gate (GG) and outer coast?
S3	13	What is the sand budget of the Bay? (Including watersheds, shorelines, beaches & GG) What is the source and transport of sand moving on and off of beaches?
W4	13	How do we resolve the conflict between policies encouraging the trapping of sediment upstream and those allowing it to flow through? -Are there opportunities here for decision science tools? -Can we identify the hurdles? -Could we use multi-criteria decision analyses tools to address sediment management alternatives?

Working Group Process

The *Sediment Budget and Supply* group decided to focus on the first two questions assigned to them, S2 and S3, which ask about a sediment budget that includes the source and transport of both course and fine grained sediment inclusive of watersheds, shorelines, embayments, and flux with the Golden Gate and outer coast. The group decided that question W4 was out of the scope of this workshop, and that it should be tabled for future workshops that might look at decision science tools.

Key Issues

Four issues were identified as being critical to the development of a sediment budget research strategy. First, the group recognized that there should be a <u>hierarchical strategy</u> for how to tackle the sediment budget of the entire Bay, either starting with budgets for individual tributaries, basins, or embayments. Next, the <u>level of resolution</u> desired for each budget component, as well as the <u>scale</u> of the budget, needs to be articulated depending on its utility. Finally, determining how to manage the <u>temporal variability of data</u> used in determining a budget needs to be addressed.

1. A <u>hierarchical structure</u> for studying budgets.
    a. There are over 100 tributaries around the Bay, only about 10 of which constitute the majority of sediment input into the Bay and are regulated
        i. Do we start with studying the whole basin or individual tributaries?
        ii. The same methodology should be applied for embayments.
2. An appropriate <u>level of resolution</u> needs to be identified for specific budgets.
3. The <u>scale</u> needs to be identified for study design.
    a. Think about what's relevant to management and restoration efforts – published annual scale work, such as annual averages, may be increasingly less useful for managers
4. The <u>temporal</u> component.
    a. Can we make confident projections using temporal data?
    b. Inter-annual variability is important

Sediment Budget Components

- Inputs to the system
    - Fluvial
    - Bluffs – unknown minor component
    - Atmospheric deposition – minor component
    - Waste water treatment – minor component
    - Geological deposits
    - Outer coast
    - Wind – likely only a historical component
    - Landslides – minor component
- Temporary storage and transport between

   - Shoals
   - Mudflats
   - Ports and Marinas (dredging)
- Sinks
   - Sediment disposal out of the Bay
   - Ocean
   - Upland
   - Beneficial reuse?
   - Flood channels
      - Storage, removal, and fate
      - Sand budget is the most data-poor
   - Dams/reservoirs
   - Export to outer coast
   - Sand mining
   - Bed deposition
   - Deposition to marshes and salt ponds

Sediment Budget Components for Embayments

If a sediment budget were to be assembled for individual embayments, the same overall methodology as for a bay wide sediment budget would be employed. However, some more specific elements would play a greater role.

- Input from smaller streams
   - May make up a disproportionately and collectively larger contribution than the 10 largest tributaries (for the whole bay), even though they are not measured.
   - The importance of each component may differ between each embayment.
- Flux between embayments
   - Can use the same methodology as that for the Golden Gate flux.
- Tidal wetlands budget
   - How do we set boundaries?
- Tidal channels
- Elevations
- Scale

Existing Data

- Rough budgets for each part of the Bay
- Macro level budget for the Delta
   - With respect to tributaries, 1m/year estimated from Delta, 1.4m/year from tributaries (Water Years 1995-2010)
- Fluvial gage data for watersheds

- USGS bed load estimates from 15 rivers from USGS to assess extreme events
    - Hard to measure, except during high flow events
- Existing annual averages of sand mined since 1974
- Outer coast import estimates from Leigh Erickson's modeling work
- Bed load input estimates from Patrick Barnard

Data Needs

- Temporal Budget
    - Daily flux
    - Seasonal flux
    - Is beneficial reuse of dredged sediment considered in or out of the system?
- Annual data on tributaries
    - Bed load
    - Suspended sediment concentrations
- Improved estimate of bed load transports from the Delta
    - Boundaries of Delta
- High resolution multi-beam bathymetric survey of the Bay bed
    - Annually or every 5 years
    - Becoming more cost effective
- Sediment stored in reservoirs and flood control channels
    - Quantity
    - Quality (texture, grain size cohesion)
    - Necessary if we want to change the sediment budget by:
        - Sending sediment through tributaries
        - Transporting sediment mechanically
- Elevation of entire Bay - tidal and subtidal
    - Especially mudflats (multi-beam + Lidar → *Rikk Kvitek's Kelp Fly*)
- Continuous monitoring of the 10 biggest channels and select smaller, steeper tributaries and embayments is needed.
    - Suspended sediment
    - Bed load
- Estimated contribution from small streams in comparison to large tributaries
- Textural quality of Bay sediment
    - Grain size (% sand vs. mud)
    - Composition
    - Cohesion

Status, Risk, and Resiliency

Group Members

Jeremy Lowe (SFEI), Bob Battalio (ESA), Theresa Fregoso (USGS)

Q I.D.	Votes	Management Questions to Address
B1	11	Are there particular shoreline areas that are most at risk from erosion and sea level rise (SLR)?
B2	11	Are there new/candidate sites for shoreline restoration where natural processes can be used, as opposed to retrofitting existing armored shorelines (i.e. using horizontal levees)
B3	11	Where should managed retreat be applied/implemented? What are the cost/benefits?
B4	9	Where is armoring no longer needed and can be removed to restore sediment supply/ transport?
B5	8	Are there areas that are currently armored where restoration back to a natural shoreline is a good option? What would be the resulting benefits and consequences to sediment supply and transport?
B6	8	What is the value of different shorelines (in terms of habitat, recreation, economics, and flood control)?
B8	7	What are the alongshore transport processes along the shorelines and what is the morphology of the coastline? (Relates to the longevity of the beach and the effects of beach nourishment in that location). Are the same transport processes in action for the different types of beaches - coarse, sand, mud, etc.?

Working Group Process

All the questions allotted to this group originated from the Day 1 shorelines brainstorming session and was not focused specifically on beaches or marshes. The *Status, Risk, and Resilience* group started by further classifying the above priority management questions into the three classes of (1) Status, (2) Risk, and (3) Resilience. The group placed almost all of the priority questions into the *resilience* class, having to do mostly with shoreline restoration or retreat, with the exception of question B1 regarding shoreline areas most vulnerable, or at *risk*, to sea level rise. Questions B6, regarding the value of the different shoreline types, was placed in the *status* class, which the group interpreted as present or current conditions or functions of the landscape.

Key Issues

The group did not have time to begin developing a research strategy for these questions. Instead, they developed a list of preliminary questions that needed to be answered in order to acquire the information necessary to address each priority management question. These preliminary questions were related to data needs and understanding the dynamics of a particular shoreline location, which provides a starting point for future work towards a full research strategy.

The group focused on the idea of <u>ecosystem services</u> and the <u>value</u> of a particular ecosystem, both <u>present and historic</u>, in the *status* class, which lead to questions about sediment transport, supply, and budget as necessary pieces of information for addressing the *status* questions. In order to address the *risk* question dealing with identification of the most at-risk shorelines areas, the group thought it first important to define what the risk itself is, and what would be lost along with the shoreline. In the *resilience* class, the discussion centered on <u>future conditions</u> – including what <u>landscape types</u> are appropriate along different shorelines, and what the desired landscape of the future looks like. The group felt that these value judgments needed to be clarified before a research strategy could be aptly developed for the *resilience* questions.

The group also discussed the urgency of these shoreline vulnerability issues, and how resilient solutions will involve thinking ahead, creating a diverse portfolio of both short and long-term actions, and considering landscape level planning units. This group recognized the importance of translating information (like hazard mapping or ecosystem vulnerability) to managers efficiently, as well as staying cognizant of the desired results for successful shoreline management decisions.

Classifying Priority Management Questions

Status:
Original Question: What is the value of different shorelines (in terms of habitat, recreation, economics, and flood control)? (B6)

Preliminary Questions:
- What is the landscape that I have and how do the different habitats function on the landscape?
    - How are they connected?
    - How will they evolve in the future?
    - How do we value the ecosystem?
    - What are the ecosystem services?
- Where am I in the Bay?
- What are the co-benefits of some of the habitat types to maintain ecosystem services?
- Why do we choose certain habitat types?

Risk:
Original Question: Are there particular shoreline areas that are most at risk from erosion and sea level rise (SLR)? (B1)

Preliminary Questions:
- What is the risk of losing this landscape/shoreline type?
- What is the risk of losing the ecosystem services and the functionality of the landscape?
- How will Bay hydrodynamics (flux) change under sea level rise?

Resilience:

Original Questions:

- Where should managed retreat be applied/implemented? What are the cost/benefits? (B3)
- Are there new/candidate sites for shoreline restoration where natural processes can be used, as opposed to retrofitting existing armored shorelines (i.e. using horizontal levees) (B2)
- Are there areas that are currently armored where restoration back to a natural shoreline is a good option? What would be the resulting benefits and consequences to sediment supply and transport? (B5)
- Where is armoring no longer needed and can be removed to restore sediment supply/ transport? (B4)

Preliminary Questions:

- How do we increase resiliency to maintain ecosystem services?
- How do we make management actions sustainable?

Strategy Follow-up

Due to the time constraints of the workshop, group members were contacted after the workshop to continue work towards clarifying a research strategy. Question *(B1) [Are there particular shoreline areas that are most at risk from erosion and sea level rise (SLR)?]* were further fleshed out for both marsh and beach shorelines types as an example of a potential research strategy. The results of this work can be found in Appendix F, Worksheets I and II. These worksheets serve as foundation for further work towards a research strategy on Status, Risk, and Resilience.

Management Linkages Group

Group Members

Mark Boucher (BAFPAA and CCCFCD), Carl Morrison (BAFPAA and Morrison & Associates Inc.), Stuart Siegel (SF Bay NERR; Siegel Environmental), Luisa Valiela (EPA), Ian Wren (Baykeeper)

Working Group Process

To address the concern that management needs may get lost from the reorganization of questions from the first day into more science process based groups for the development of research strategies, one group, comprised largely of managers that attended the second day, decided they would work solely on fleshing out the management linkage. This group aimed to explicitly draw the connection between the management implications of the priority questions, and their importance for the region.

Management Linkages General Discussion Points

1. The group's objective was to identify:

a. What are the management decisions that are currently being made?
    i. Are they near, medium, or long-term?
        1. Example <u>management decisions</u> include: Decisions on permits and projects, where to allocate money, land acquisitions, coastal land use zoning and planning, general plans, Bay fill policies and adaptation, dredging and disposal options, flood protection project de-authorization, restoration priorities, infrastructure at risk, etc.
    ii. Are they preventative, responsive, or based on recovery?
b. Who are the decision-makers?
c. Who are the users of decisions?
d. What are the outcomes of decision-making, and is the science successfully informing those decisions?
    i. For example, if you take a management action and it is successful, what are you getting? This is considered an <u>ultimate outcome</u>. Examples of ultimate outcomes include:

Management Sector	**Ultimate Outcome**
Existing marshes and mudflats	Maintenance of function and services (both ecological and protection) now and in the future with sea level rise (SLR)
Diked and subsided bayland restoration sites	Restoration of functions to increase resiliency to SLR
Horizontal levees, living shorelines, and beaches	Understanding of efficacy in providing viable shoreline protection
Flood protection	Protection of life and property from rivers, creeks, and coastal flooding Minimization of the need for dredging creeks, rivers, and navigational channels
Dredging	Maintenance of commercial and recreational navigation for ports and marinas
Sand mining	Meeting the construction aggregate needs for the region
Water Quality - TMDLs	Cleaner sediment that can be reused (e.g. through limits on hydrophobic contaminants)
Beneficial reuse	Maximization of cost-effective strategies for beneficial reuse

Key Issues

Although this group did not explicitly draw out the management linkage from each priority question that the *Fate and Transport*, *Sediment Budget*, and *Status, Risk, and Resiliency* groups were discussing, they demonstrated a thought process that should be exercised when prioritizing or developing a research study for any of these sediment issues. They illustrated the importance of defining the end goal of any research study and exactly how the resulting science would benefit and inform future decision-making by managers.

Conclusion and Next Steps

This workshop was successful at accomplishing the desired goal of identifying the most important sediment-related management questions for the region. Additionally, through this work, we have documented a prioritized list of these questions, which can be referenced in the future when seeking funding.

Furthermore, through this process we developed the initial components of a research strategy for three scientific groups: 1) Fate and Transport, 2) Budget and Supply, and 3) Status, Risk, and Resilience. From these pieces, we can identify several overlapping monitoring and data needs that will benefit the region.

Monitoring and Data	Research Need Addressed	Management Need Addressed
• Bay wide bathymetry below mean lower low water (MLLW) • Bathymetry of the Bay bed	• Accurate modeling efforts • Informing the sediment budget	• Monitoring shoreline change and identifying risks • Decisions about handling the disposal of dredged sediment and permitting of sand mining
• Region-wide, annual, continuous monitoring of suspended sediment concentrations and bed load of major channels, steep tributaries, and embayments • Varying across time, space, tidal cycle, season, and climate	• Predicting marsh accretion rates • Modeling sediment movement • Understanding sediment supply from both watersheds and Bay	• Informing the permitting of restoration projects • Better management of flood control channels and dredging projects

In order to continue developing a cohesive and comprehensive research strategy for the region, we propose creating a working group for each of the three scientific groups. Through a series of working group meetings through the spring of 2016, these groups would build off of what was generated from the workshop, drafting individual research programs for each group. A consolidated draft strategy would be circulated to interested parties for feedback and review before being finalized.

Ultimately, continuation of this work will accomplish the following four critical regional objectives:

- Understand how much of what type of sediment we have, and where;
- Increase fluvial and tidal connections to improve sediment conveyance;
- Increase the beneficial reuse of sediment in the context of a limited incoming supply in order to maintain wetlands;
- Identify shorelines at risk from sea level rise and ways to reinforce them through sustainable means, mimicking natural systems.

BCDC is grateful for the support of the individuals and organizations that supported the development of the workshop and participated, offering their thoughts, expertise and priorities for regional sediment science, and to those who do the science that informs the management of the Bay resources.

Appendix A

Pre-workshop Management Question Rating Responses

Sediment-related Sector	Sediment Management Questions	Number of Responses		
		Highly Relevant	Somewhat Relevant	Irrelevant
Beaches	What are the seasonal variations in beach shape due to erosion/accretion?	1	2	1
	What kind (shape) of beach do I have? Is it erosional?	2	1	1
	What controls sand deposition or stability of my beach?	3	0	1
	Can I use beaches to protect areas behind them?	3	0	1
	Does it make "sense" to nourish my beach?	1	2	1
	What is the grain size of my beach, and does it matter?	3	0	1
	What are the effects of changing the slope of my beach?	2	1	1
	Should I move sand around on my beach?	1	1	2
	Where does the sand come from?	2	1	1
	How well does sand attenuate wave action/energy?	3	0	1
	How will my beach evolve as sea level rises? Is it sustainable?	3	0	1
	Are sand dunes important to beach sustainability?	2	1	1
	What are suitable methods for protecting beaches?	3	0	1
	How do we manage coarse Bay sediment at the regional level for use in the Baylands in a way that allows sand to move through the Bay under natural forces to create and replenish barrier beaches?	2	1	1
Shorelines	How will my shoreline evolve as sea level rises? Is it sustainable? How will sea level rise and increasing storm intensity affect flood protection offered by my shoreline?	4	0	0
	Which areas are best for living shorelines based on existing conditions?	3	1	0

Shorelines	How does the placement of artificial structures impact subtidal habitat function and sediment flow/transport to and from these areas?	2	2	0
	Which types of shorelines (natural and unnatural) are complimentary to each other for resiliency or shoreline protection?	3	1	0
	Are there armoring techniques, placement, angle, or materials that are less harmful/more beneficial?	2	2	0
	How does shoreline protection affect sediment transport?	3	1	0
	What is the sediment transport process in various embayments or localities?	2	2	0
	What is the major sediment source for my shoreline?	4	0	0
	Do I have/need subtidal shoals to protect my shoreline?	1	3	0
	Are there identifiable patterns of sediment deposition and erosion along shorelines?	4	0	0
Sediment Transport	What is the relationship of sediment depletion (either from dredging or erosion) to sand/sediment supply and the overall sediment budget?	5	0	0
	What is the timeframe in which we expect to see significant changes to our system/shorelines from coastal flooding or scarp erosion?	2	3	0
	How much sand leaves the Bay to outer coast beaches?	2	2	1
	How much sand is coming from landside erosion?	1	3	1
	How much sand is coming from tributaries and flood control channels?	2	2	1
	How does sand get from tributaries to sand shoals?	1	3	1
	Does sand move between embayments?	0	4	1
	How does fine sediment move between embayments?	2	3	0
	How much sediment leaves the Bay and how much enters through the Gate?	3	2	0
	Can we describe/define near-shore sediment transport along different sections of the Bay (locally or regionally)?	4	1	0
	How deep are the sediment deposits throughout bay to the Bedrock, or what portion is made up of sand?	2	2	1
	Which parts of the bay are more stable or erosive? (Locally and regionally)	5	0	0
	Can we describe the bay floor sediment types, elevation, and wave action?	2	3	0
	How does the San Francisco bar protect or harm the Bay?	3	1	1

Sediment Transport	How do deep-water sand shoals outside the Bay influence tidal/subtidal hydrology inside the Bay?	2	2	1
	How do the sand shoals inside the Bay influence tidal hydrology/subtidal hydrology within the Bay?	2	2	1
	How does opening up additional upland beneficial reuse sites affect the tidal prism and sediment rates (i.e. Mare Island Dry Dock)	3	2	0
	Where and how should we manage sediment to achieve goals in different subregions of the Baylands?	5	0	0
	With climate change and sea level rise, will we have more sediment depositing in the Bay from the ocean?	5	0	0
Dredging or Salt Pond Restoration	What is the shoaling rate of sediment in my berth/project area?	6	4	3
	What is the long-term fate of aquatic disposal of dredged sediment and disposal plumes? Is an eelgrass bed buffer needed/effective?	5	7	1
	Does the water coming into the Bay equate to less sediment in our channels/berths/marinas?	7	4	2
	How do adjacent projects impact my project?	5	5	3
	Will placing dredged sediment in Bay work to augment marshes or mudflats? What are the water quality implications of this?	10	0	3
	Is the Bay moving to a new normal in terms of a sediment balance? When or will it stabilize?	6	6	1
	Is the bay really clearing, i.e., decreasing in sediment?	7	4	1
	What will clearing mean nearshore and in deeper water?	5	6	2
	Would dumping dredged sediment in the Bay help minimize the impacts of clearing?	8	2	3
	Where is my sediment coming from?	7	3	3
	What is the effect of removing sediment from the Bay?	6	3	4
	What do we consider the sediment system? What is the "whole"?	7	1	4

Marshes and Mudflats	What is the accretion/erosion rate of marshes (local/regional), and how is it expected to change with sea level rise?	5	0	0
	How do I determine the "status" of my marsh in terms of sea level rise?	5	0	0
	Will planting vegetation (and what type) help accrete soil?	2	2	1
	How do/should we assist vertical accretion of marshes or help them grow (prograde)?	5	0	0
	What happens to mudflats as marshes prograde?	3	1	1
	How will my mudflat evolve as sea level rise?	4	1	0
	What happens to "downstream" (or upstream) marshes when a new or enhanced marsh traps sediment?	4	1	0
	How will restoring tidal connections to the Bay affect sediment availability for mudflats?	3	2	0
	Can I place sediment in subtidal areas and trap that sediment on nearby marshes and mudflats?	3	1	1
	Do mudflats need augmentation?	3	2	0
	What characteristics of shorelines lend themselves to cross-shore integration between subtidal and wetland projects?	4	1	0
	What kind of transition zone/slope is appropriate for upland transgression in the face of sea level rise?	4	1	0
Marshes and Mudflats	How does sediment change as you move away from its source channel?	1	3	1
	What is the best way to trap sediment?	3	2	0
	What is the net sediment flux in and out of a marsh?	3	2	0
	What are suitable methods for protecting mudflats?	5	0	0
	How much suspended sediment is adjacent to my marsh in rivers or the Bay? How does it get onto my marsh? Is it enough? Is there anything we can do to augment it?	4	1	0

Flood Protection	How does the flux of sediment from the Bay compare to that from watersheds? How far up the watershed does sediment travel?	3	3	3
	How quickly does sediment move through the channel and to the Bay?	4	5	0
	Where/why/when does the sediment get caught?	5	4	0
	Does the geological setting of my watershed affect sediment transport?	4	5	0
	What is the role of the physical setting on sediment transport? (E.g. the eastern edges of the Bay can be downwind more often and see greater wind-wave re-suspension).	1	6	2
	How does land elevation/topography affect sediment flows?	3	4	2
	How far/fast does water need to flow to move different sized sediment particles?	2	6	1
	Does channel realignment make sense for conveyance?	5	4	0
	What type of channel geometry supports stable shorelines?	4	5	0
Watershed and Land Management	How do I prevent erosion/sediment loss?	6	2	2
	What features (natural/engineered) can I include to retain sediment?	6	4	0
	How does sediment move through my watersheds?	7	2	1
	What grain size of sediment is coming down my creek/channel?	3	6	1
	How do grain sizes influence sediment movement/transport?	5	4	1
	How do I slow/increase the rate of water/sediment movement?	6	4	0
	Why is sediment important and what grain sizes are important to keep in my stream?	4	4	2
	How can we change watershed management practices to increase sediment inputs/delivery to marshes or the Bay?	5	4	1
	Are there opportunities to integrate wetlands restoration with watershed management in order to take advantage of associated freshwater and sediment pathways?	8	0	0

Models	What are the data and information gaps that need to be filled to develop a reliable sediment transport model?	3	1	0
	What are the management objectives for a numerical sediment transport model?	2	2	0
	Is it possible to develop a standard model with appropriate variables used throughout (which may have different standards for permitting purposes versus scientific study)?	3	1	0
Monitoring	Velocity is necessary to infer sediment flux magnitude and direction. How are sediment gages optimally distributed (in tributaries, shoals, and intertidal deep water channels)?	2	3	0
	Is it possible to develop a regional database to house monitoring data?	4	0	1
Suggested Priority Management Questions from Pre-Workshop Survey	Do we have an appropriate institutional network of agencies and academic institutions to provide comprehensive solutions to sediment management problems?			
	If we were approaching high level decision makers about the top three sediment management priorities for the San Francisco Bay Area - what would they be?			
	Where are the next locations for beneficial reuse sediment placement?			
	How can the cost of disposal at beneficial reuse sites be reduced?			
	How would Bay clearing affect eelgrass and other subtidal habitats in the context of sea level rise?			
	For a typical watershed, how has sediment yield changed over time? Have BMPs helped or hurt in the big picture of a healthy sediment supply?			
	Is it true that poorly managed rangeland (overgrazing) yield more sediment input per acre than an already developed neighborhood?			
	How can we economically determine the boundary between where estuarine and riverine forces govern sediment deposition? And what differences in sediment (grain size, contaminants, etc.) are found between these two deposition methods.			
	How can we better identify both opportunities and constraints associated with strategies for sediment management within our watershed? What tools are out there? Is historical ecology study the best option?			
	How much room do my various creek channels need to be dynamically,			

Suggested Priority Management Questions	geomorphically stable?			
	What are the most important watershed sources of creek sediments, overland flow erosion or creek bank erosion?			
	Where is it settling (we already know that, but need to assess its flood protection impacts)			
	Can we redesign our channels to naturally convey the sediment out to the bay, where it will be useful?			
	Can we naturally augment spawning gravels by design? We are currently mining and depositing them for spawning habitat?			
	How do recreational land uses increase erosion and sediment loss? How can this efficiently be measured over time?			
	How have past land management regimes (agriculture) impacted erosion and sediment discharge and how can watersheds recover from this? How can we address severe erosion, down-cutting channels and creation of channels in new locations, all of which lead to a large increase in fine sediment?			
	What is the effect of long and short-term turbidity? On what timescales should we be concerned?			
	How should we manage sediment to maintain/maximize/increase habitat in the face of sea level rise? What are the gaps in our understanding that we should address in research to accomplish that goal?			
	How should we manage sediment to ensure that there are alternatives to shoreline armoring to adapt to sea level rise? What are the gaps in our understanding that we should address in research to accomplish that goal?			

Appendix B

Workshop Team (Days 1 and 2)

First Name	Last Name	Affiliation
Lauren	Garske	CCC
Brenda	Goeden	BCDC
Maya	Hayden	SF Bay and Outer Coast Sentinel Site Cooperative
Anniken	Lydon	BCDC
Greg	Ogata	BCDC
Elena	Perez	CCC
Heather	Perry	BCDC
Pascale	Soumoy	BCDC

Participants (Day 1)

First Name	Last Name	Affiliation
Melisa	Amato	San Pablo Bay NWR
Brian	Baird	The Bay Institute and Aquarium of the Bay
Chris	Barr	USFWS - SF Bay NWRC
Bob	Batha	BCDC *
John	Bourgeois	State Coastal Conservancy
John	Callaway	USF
Beth	Christian	RWQCB
Caroline	Christman	Golden Gate National Parks Conservancy
Laurel	Collins	Watershed Sciences
Dan	Cunning	EBRPD
Maureen	Downing-Kunz	USGS
Theresa	Fregoso	USGS
Doug	George	Applied Marine Sciences, Inc.
Letitia	Grenier	SFEI *
Mark	Johnsson	CCC
Jessie	Lacy	USGS
Jeremy	Lowe	SFEI
Lissa	MacVean	UC Berkeley, Stanford
Michael	MacWilliams	Anchor QEA
Brad	McCrea	BCDC *
Lester	McKee	SFEI
Carl	Morrison	BAFPAA and Morrison & Associates Inc.
Brian	Ross	EPA
Sandra	Scoggin	SFBJV
Dave	Schoellhamer	USGS
Stuart	Siegel	SF Bay NERR; Siegel Environmental
Jeffery	Steevens	USACE – ERDC

Miriam	Torres	BCDC *
Philip	Trowbridge	SFEI
Luisa	Valiela	EPA
Sarah	van der Schalie	NOAA – OCM
Michael	Vasey	SF Bay NERR
Kristen	Ward	GGNRA
Louis	White	ESA
Anne	Whittington	Port of Oakland
Ian	Wren	Baykeeper
Liang	Xu	SCVWD

* = Was not able to participate in the brainstorming session
= Started in the Open Bay and Subtidal Areas brainstorming rotation
= Started in the Marshes and Mudflats brainstorming rotation
= Started in the Watersheds, Tributaries, and Flood Control Channels brainstorming rotation
= Started in the Beaches and Non-wetland Shorelines brainstorming rotation

Participants (Day 2)

First Name	Last Name	Affiliation
Bob	Battalio	ESA
Mark	Boucher	BAFPAA and CCCFCD
John	Callaway	USF
Laurel	Collins	Watershed Sciences
Maureen	Downing-Kunz	USGS
Matt	Ferner	SF Bay NERR
Theresa	Fregoso	USGS
Oliver	Fringer	Stanford
Doug	George	Applied Marine Sciences, Inc.
Mark	Johnsson	CCC
Jessie	Lacy	USGS
Jeremy	Lowe	SFEI
Lissa	MacVean	UC Berkeley, Stanford
Michael	MacWilliams	Anchor QEA
Lester	McKee	SFEI
Carl	Morrison	BAFPAA and Morrison & Associates Inc.
Dave	Schoellhamer	USGS
Stuart	Siegel	SF Bay NERR; Siegel Environmental
Jeffery	Steevens	USACE – ERDC
Luisa	Valiela	EPA
Laura	Valoppi	USGS
Ian	Wren	Baykeeper

Appendix C

Prioritized Management Questions by Geographic Sector

Q I.D.	Votes	Watershed, Tributaries, and Flood Control Questions	Small Group Theme
W1	18	How can we design channels to help convey sediment to marshes/baylands rather than into the Bay?	Conveyance
W2	15	What do we estimate to be the change in sediment supply/erosion of our watersheds into the future (using modeling)?	Supply & Fate*
W3	13	Where can we reuse dredged sediment from channels—nearby, locally, and cheaply?	Fate
W4	13	How do we resolve the conflict between policies encouraging the trapping of sediment upstream and those allowing it to flow through? -Are there opportunities here for decision science tools? -Can we identify the hurdles? -Could we use multi-criteria decision analyses tools to address sediment management alternatives?	Supply
W5	13	How do we better link our flood plains with our marsh plains?	Fate
W6	9	Can we avoid the trapezoidal channel? Is there a more natural channel design/shape/form that doesn't require dredging and also provides adequate flood control and habitat benefits? How would this modify the tidal prism and flow? Will additional space for water flow also require additional sediment? Does the widening of channels simply buy a few years before requiring dredging again? Is the 100-year flood still the correct element to use in basing channel designs from?	Conveyance
W7	9	What is the efficacy of horizontal levees/ecotone slopes?	Fate
W8	8	How much sediment is stored in reservoirs/dams? What is the grain size, texture, or contamination (mercury)? How do we access this material? Can it be reused? What is the total quantity of this as a resource? How do we get it to the Bay?	Supply & Material^
W9	5	Are there places where you could do in-Bay placement that disperses and is not harmful?	Fate
W10	3	How have past land management regimes (and regulatory environments) impacted erosion/sediment supply?	Supply
W11	3	What are the suspended sediment concentrations in the near shore estuary?	Supply & Material
W12	3	How much sediment, regionally, is in our flood control channels? What is the grain size, texture, and contamination?	Supply & Material
W13	2	What differences in sediment are found between estuarine versus fluvial deposition processes? How do we determine the boundary?	Supply
W14	2	How much sediment comes into my channel from the Bay?	Supply & Material
W15	2	What are the true water quality impacts of strategic in-Bay disposal? Can we broaden the definition of beneficial reuse?	None
W16	1	Where can we put sediment to attenuate waves before/in front of levees?	Fate

W17	1	Could life-cycle analyses tools be implemented in decision making to help understand the sediment system and move away from single objective to multi-objective management? (Looking at the life cycle of sediment in the Bay, dredging activity -- air quality impacts, energy cost, etc.)	Fate
W18	0	Is overland flow erosion or creek bank erosion the primary watershed source of sediment?	Supply
W19	0	Is there a way to help Baylands trap sediment?	Fate & Conveyance
W20	0	Should we be building up the upland transition areas rather than marshes?	Supply
W21	0	To what extent does TMDL monitoring actually inform suspended sediment entering the Bay? Are we using the data? Only a few watersheds are regularly monitored for suspended sediment concentration-- How do we determine loading rates of watershed?	Supply & Conveyance
W22	0	What is the best design for building 'green' levees/dikes for flood protection and wave attenuation (i.e. low marshes in front of dykes)? Can we enhance natural levees to buy time for engineered structures? Where can they work in tandem? How do we stay within the existing levee size?	Conveyance
W23	0	Where can we place sediment that will help build the largest areas? (i.e. where tides are already carrying sediment?)	None
W24	0	Should we be placing sediment in subsided baylands as opposed to placing it higher up in transition areas (and where)? Will they keep up with SLR, or can we manage for the inability to do so, and place the sediment further upland? Are we moving into future management of the bay with narrow fringe marshes with more sediment needed on the backsides of baylands and upland? In other words, how do we define and describe tributaries, marshes, and wetlands, and how do we work with their natural tendencies and manage them accordingly for sea level rise?	None
W25	0	Would alluvial fan restoration be a good mechanism to trap/store sediment where fan function has been lost or disconnected? Could restoring alluvial fans help reduce flooding and be used in upper watersheds to reduce sediment deposition in lower flood control channels?	Conveyance & Supply
W26	0	Can we quantify the amount of sediment that has filled in tidal sloughs (narrowing them) over the past 100 years?	Fate & Supply
W27	0	Can we determine better loading rates for our tributaries, flood control channels, watersheds?	Supply
W28	0	What are the main criteria needed for planning of watershed management?	Supply & Fate
W29	0	What is the natural change in sediment supply (what is the change causing the sediment deficit) and what are the management consequences (how does sand mining/dredging fit in)?	Supply
W30	0	Are there locations where we can allow flood plains to expand?	Fate
W31	0	How much additional sediment entering the Bay from flood control channels is beneficial? How do you balance too much incoming sediment accreting (i.e. for marinas) with the benefits it provides subtidally?	Fate

W32	0	What is/can we influence the base flow/sediment pulse from flood control channels? Is the build up of sediment around mouths of channels good for the Bay or the system? During flood years, would a flushing be a consideration for pushing accreted sediment out to the Bay? During low flow years, sediment may deposit in small amounts all along the watershed - is this good or bad? How does this work in drought areas?	Conveyance & Material
W33		Can we estimate changes in sediment supply over the next 50 years within local tributaries and watershed? (Consider climate change impacting rainfall -- decreasing annual rainfall events yet increasing the amount of rain falling during events). How will this impact the watershed reaction to precipitation?	Not included on flipcharts for voting
W34		Are there naturally occurring contaminants? How will their distribution and fate be impacted by climate change and how can we use this sediment appropriately and more efficiently?	Not included on flipcharts for voting
W35		What is the geological stability of watershed zones, and what is their landslide potential? How much do we know about the stability of watersheds and erosion rates? (Some watersheds are more mixed and will even store the sediments -- South Bay watersheds may be more characteristic of this).	Not included on flipcharts for voting
W36		In order to model sediment movement, we need to know the suspended sediment concentration near mouths of channels -- What is the watershed sediment supply? What are the tidal concentrations of sediment coming in from the Bay?	Not included on flipcharts for voting
W37		What are the boundaries of watersheds? (Rip rap, hardscape, natural shoreline)	Not included on flipcharts for voting
W38		How can we link the Bay, outer coast, tributaries, watersheds, flood plains, and marsh plains in a way that allows for flood control and enhances sediment flow to the Bay?	Not included on flipcharts for voting
W39		Where is sediment naturally accreting in channels and what are opportunities in those locations for use of sediment and development of better designs based on the accretion rates?	Not included on flipcharts for voting
W40		Can we design the entrance of flood control channels to be more conducive to sediment transport as opposed to sediment trapping?	Not included on flipcharts for voting
		*Fate = Current and future sediment fate and transport ^Sediment= Sediment storage/texture/grain size	

Q I.D.	**Votes**	**Marshes and Mudflats Questions**	**Small Group Theme**
M1	18	How can we verify or test (i.e., through pilot study) the modeling results of in-Bay placement naturally redistributing to marsh plain, leading to more efficient "beneficial reuse"?	
M2	13	How and where do/should we assist vertical accretion of marsh/mudflats? (a) viability of thin layer deposition of dredged sediment in marshes; (b) reconnecting flood control channels to marshes; (C) effectiveness/timing/ location of sediment placement (source replenishment) on mudflats for redistribution onto marshes; (d) criteria to prioritize locations for marsh conservation or restoration	
M3	12	What is the predicted "new normal" for suspended sediment concentrations (a critical driver for predicting marsh accretion rates), and how does it vary spatially and temporally around the Bay? (Necessary input for marsh models)	

M4	12	How can we design an integrated monitoring program (i.e. water levels, accretion rates, sediment supply) of both natural and restored marshes to aid in future restoration designs? Can we use the data-driven transfer of lessons learned from existing restoration projects to aid in improving designs for newly planned restoration efforts?	
M5	10	What is the best percentage of sediment that we can get to naturally redistribute from in-bay placement to the mudflat/marsh plain, and what percentage of successful redistribution is necessary to be considered “beneficial”?	
M6	10	What factors determine marsh resilience to sea level rise (e.g. location, deposition/erosion, impact of adjacent mudflat morphology), and how can this information help us to understand the potential longevity of our investments in marsh restoration?	
M7	8	Are there engineering solutions for increasing the cost-effectiveness of beneficial reuse, such as the proposal to dump sediment on the bay outside of Hamilton and have tides move it, or an aquatic transfer facility?	
M8	6	What is the functional size of area needed to support self-sustaining/functioning marshes and systems?	
M9	5	How is the hydraulic geometry of tidal sloughs or tributaries influencing sediment transport? Where do we want the sediment to go?	
M10	5	What factors are needed to identify optimal locations for marsh restoration? Are there remote sensing approaches?	
M11	5	What is the optimal design of transition zones (to upland) and horizontal levees?	
M12	4	What is the wave climate around my marsh, and how does it impact erosion/deposition? How will wave climate impacts change with SLR?	
M13	3	What is the elevation capital necessary for marsh resilience?	
M14	2	How do we determine locations of priority conservation/restoration of marshes?	
M15	2	Could we use historic subsidence as a proxy for marsh response to SLR (e.g., using Alviso Slough)?	
M16	2	To retain/restore enough marshes/mudflats for the next 100 years: (a) How much sediment could we get if we were to change the management of all sources of sediment (e.g., if we had access to all sediment sources)? (b) If we could get all sources, how much more ‘marsh acre years’ would we get? (c) Consider context (sea level rise, restoration, sediment transport and fate, time/space/cost considerations).	
M17	1	What is the accretion/erosion rate of marshes (locally and regionally), and how is it expected to change with sea level rise?	Seeder Question
M18	1	Is large-scale marsh restoration eroding mudflats? (What are the potential trade-offs between marshes and mudflats?)	
M19	1	What is the necessary sediment supply to meet desired management needs/outcomes, and how can we connect sediment supply to meet management needs that are regionally varied?	
M20	1	How can we incorporate historic geomorphic landscapes into restoration designs (e.g. more holistic ecotones, pannes, or back barrier lagoons)?	
M21	1	What is the vertical land motion (tectonically) in relation to SLR?	
M22	0	How do I determine the “status” of my marsh in terms of sea level rise?	

M23	0	How are sediment dynamics (supply) changing and how will that affect marsh resiliency?	
M24	0	How will backwater flooding (resulting from SLR) affect deposition and distribution of sediment in marshes?	
M25	0	What are the distributary channel systems in deltas/fans?	
M26	0	How do we expand/scale up living shorelines to help protect against marsh and mudflat erosion? Can we use oyster beds and eelgrass to enhance living shorelines?	
M27	0	Do we have enough natural marsh sentinel site locations to project the future of marsh resiliency (long term change over time)?	
M28	0	Contaminants (are sediment now "cleaner")? What are the biological impacts?	
M29	0	Can we use marshes as a filter for dredged sediment contaminants (paradigm shift)	
M30	0	What are more resilient designs for future marsh restoration projects?	
M31	0	What is the rate of loss of marsh due to lateral processes (such as waves or lower mudflat protection)?	
M32	0	What services/functions/processes of sediment need to be studied in order to understand the vulnerability of mudflats to sea level rise?	
M33		What kinds of mudflats do we actually have? Are they concave (leading to more wave attack), or convex (meaning there will be less wave attack)?	Not included on flipcharts for voting
M34		How do you determine what accretion is possible from natural processes with increased sea level rise? How do you determine if the natural accretion will be enough?	Not included on flipcharts for voting
M35		What baseline will we evaluate future change from?	Not included on flipcharts for voting
M36		What is the resiliency of my mudflat, and how to I assess it?	Not included on flipcharts for voting

Q I.D.	Votes	Beaches and Non-wetland Shoreline Questions	Small Group Theme
B1	11	Are there particular shoreline areas that are most at risk from erosion and sea level rise (SLR)?	Where
B2	11	Are there new/candidate sites for shoreline restoration where natural processes can be used, as opposed to retrofitting existing armored shorelines (i.e. using horizontal levees)	Where
B3	11	Where should managed retreat be applied/implemented? What are the cost/benefits?	Where
B4	9	Where is armoring no longer needed and can be removed to restore sediment supply/ transport?	Where
B5	8	Are there areas that are currently armored where restoration back to a natural shoreline is a good option? What would be the resulting benefits and consequences to sediment supply and transport?	Where
B6	8	What is the value of different shorelines (in terms of habitat, recreation, economics, and flood control)?	Why, Where
B7	8	How do we reuse dredged coarse sediment for beach nourishment and dune restoration?	How

B8	7	What are the alongshore transport processes along the shorelines and what is the morphology of the coastline? (Relates to the longevity of the beach and the effects of beach nourishment in that location). Are the same transport processes in action for the different types of beaches - coarse, sand, mud, etc.?	
B9	7	What is the functionality of the particular area of shoreline, now and in the future, i.e., what ecosystem services does it provide)?	Why
B10	4	How do we manage sediment for sustaining beaches/habitat in the face of sea level rise? (Need to identify gaps in understanding)	
B11	4	How can infrastructure (i.e. roads, bridges, rail) be designed/engineered/modified to accommodate natural processes?	How
B12	3	What types of beaches/shorelines are currently occurring, and which ones are appropriate in different parts of the Bay? What are their historical locations? How have they changed in size and shape?	Where
B13	3	Where is sediment needed along the shoreline? Is there a shoreline map showing the geographic locations of sediment issues? Accretion and erosion?	Where
B14	3	What is the habitat value of beaches in the Bay?	Why
B15	3	What are the run-up and overtopping implications/rates from holding a structure's line vs. restoring a natural shoreline/beach over time?	How
B16	2	Are there ways we can redesign armored shorelines to provide habitat values and beach/recreation opportunities that also address sea level rise (e.g. incorporating natural groins or living shorelines, removing piles, or adding a vegetative bench in the midst of rip rap)?	How
B17	2	What is the source of sand for the beach? Where is it going if it is eroding?	
B18	2	What are ways to manage sand mining materials so it is more appropriate for reuse?	How
B19	1	What controls deposition/stability of my beach?	
B20	1	In the armored areas, do we know where the armoring reflects the low-high tide? Is there a catalogue or map of the different armoring elevations along the shoreline relative to MLLW?	
B21	1	Are there different parts of the Bay that have processes that can support or maintain beaches? Are there parts of the Bay that better lend themselves to the natural sediment transport system than others? What can we learn from these areas?	Where
B22	1	Which beaches are most resilient to sea level rise and why? (Akin to a Goals Project for Regional Sediment Management)	
B23	1	What kinds of beaches do we have, what is their morphology, and where are they? What is their connection to back beach dunes? Mudflats – Beach – Dune – Seasonal Wetlands.	Where
B24	1	Is beach nourishment a good management strategy? What are the ecological impacts of doing or not doing nourishment? What are the benefits of trying to create a sandy beach where it wouldn't occur naturally vs. augmenting at a location where erosion/accretion is occurring (e.g. Crown Beach)?	

B25	1	Are certain sand mining/dredging activities contributing to a greater level of erosion in particular locations/beaches?	
B26	1	What is the nearshore wave climate in the Bay?	How
B27	1	What types of materials are best for beach restoration/construction? Experimentation examples? Non-traditional materials?	How
B28	1	How can we quantify the different ecosystem services of different habitats in the Bay? What makes beaches qualitatively different?	Why
B29	1	How much room is needed for a beach to maintain itself, given sea level rise?	How
B30	1	How do/can we integrate waste water effluent into shoreline restoration and design?	How
B31	0	How do we manage sediment to ensure alternatives to shoreline armoring?	
B32	0	What is the shape/size of the channel, and how does it affect the transport of different sized material? Can it be altered to achieve the desired size?	
B33	0	What are the effects of non-native grain size placement in beach nourishment projects?	How
B34	0	What was the historical location of naturally occurring beaches vs. where we have beaches now? How have they changed in size and shape? Where were the historically hardened shoreline areas?	
B35	0	What is the evolution and trajectory of a shoreline at a particular location?	
B36	0	Are marsh erosion and beach erosion processes the same? In comparing a marsh to a beach, which is more effective as a technique to address sea level rise?)	How
B37	0	Can beaches be used to protect more sensitive shoreline areas (i.e. beaches fronting marshes)?	How, Where
B38	0	How long will beach nourishment last (i.e. at Ocean Beach)? Where does the sand go?	
B39	0	What are the appropriate wind-blown sand control measures in the Bay?	How
B40	0	How do management activities impact tidal amplification and sediment transport (i.e. in South Bay)?	How
B41	0	What historic landscapes that are missing can be reintroduced (e.g. horizontal levees or ecotones)?	How
B42	Not voted on	There is an ocean side pipeline that pushes sand through to replenish the beaches -- Is there something like this in the Bay Area?	
B43	Not voted on	Where might beaches be more useful in the future?	
B44	Not voted on	What are the effects of changing the slope of the beach?	

Q I.D.	Votes	Open Bay and Subtidal Areas Questions	Small Group Theme
S1	18	Does the placement of dredged sediment at in-Bay disposal sites help with shores and wetlands?	Management Implications
S2	14	Can we develop sediment budgets for embayments, tributaries, and the flux between the Golden Gate (GG) and outer coast?	Existing Conditions

S3	13	What is the sand budget of the Bay? (Including watersheds, shorelines, beaches & GG) What is the source and transport of sand moving on and off of beaches?	Management Implications
S4	12	How would deeper water (due to sea level rise) affect sediment deposition dynamics of mudflats and shallow subtidal shoals?	Future Conditions
S5	10	Is the Bay really clearing?	*Used as seeder question
S6	10	Can we increase sediment supply?	Management Implications
S7	6	Can we reduce sand demand?	Management Implications
S8	5	How do dredge-deepening projects affect sediment transport (locally and regionally)? Are there design opportunities to improve sediment transport through dredging?	Management Implications
S9	4	Do dredging and sand mining affect sediment supply and transport, and vice versa?	Management Implications
S10	4	Does the sand mined relate to Gold Rush pre-hydraulic – did it have less sand? Are we going back to more natural loads and should we adapt?	Management Implications
S11	4	How much sediment is stored in flood plains and the Bay?	Existing Conditions
S12	3	Is the sand being mined historic or in transport? Are we moving towards historic levels of sand transport? Should we adapt?	Existing Conditions
S13	2	Can sediment be used to address sea level rise -- can we use dredged sediment to supplement sediment deposits around the Bay?	Management Implications
S14	2	Will sea level rise affect how sediment is transported?	Future Conditions
S15	2	Needed data for accurate models – 2015 Bay wide bathymetry; texture of Bay bottom; distribution of benthic organisms	Existing Conditions
S16	1	Does sand supply influence shoreline accretion?	Existing Conditions
S17	1	Are local beaches affected by erosion/accretion of the SF Bar?	Existing Conditions
S18	1	How are fine grains mobilized and transported to South SF Bay?	Existing Conditions
S19	1	What is the "shoreline" (long shore) transport of Bay sediments?	Existing Conditions
S20	0	When will we reach a new normal in terms of sediment loading into the Bay, and what are the implications on subtidal habitat and dredging?	*Used as seeder question
S21	0	What is the effect of long vs. short-term turbidity?	*Used as seeder question
S22	0	Can we bring in sediment to subsided lands?	Management Implications
S23	0	Assuming sediment supply has moved due to mining and dredging, could we make a map of shoreline areas to protect (place sediment) from sea level rise?	Management Implications
S24	0	How do we manage for changes to sediment transport?	Future Conditions
S25	0	Do large-scale projects/changes such as (a) deepening at the Port of Stockton and Sacramento deep-water channels; (b) catastrophic loss of Delta levees, or (C) barriers at the Golden Gate, affect sediment transport to the Bay?	Future Conditions

S26	0	What is being stored in dams and flood channels?	Existing Conditions
S27	0	What replaces sand mined from the SF Bar? What is the flux of sand at the Golden Gate?	Existing Conditions
S28	0	Is sand coming from watersheds? Where? What are the loads?	Existing Conditions
S29	0	What are the impacts of dams/reservoirs on sand supply?	Existing Conditions
S30	0	Can we identify sediment transport patterns – locally, at sub-embayments?	Existing Conditions
S31	0	What is driving sediment transport?	Existing Conditions
S32	0	If the Bay is getting deeper, is dredging/mining contributing? At what scale?	Existing Conditions
S33	0	When is the “first flush” signal expressed in the Bay? Is this signal influencing dredging?	Existing Conditions
S34	0	How do deep-water channels affect sediment transport?	Existing Conditions

Appendix D

Research Strategy Worksheet - Blank

Management question(s) being addressed

Identify the priority management question(s) from Day 1 of the workshop being addressed by this strategy. Include origin "sector" (watershed, marsh/mudflat, other shoreline, bay/subtidal).

Research Question(s)

The question should identify the underlying knowledge gap in Bay Area science/understanding related to physical sediment processes that can directly address the above Management Questions.

What do we already know?

-Existing data, projects, resources, or understanding based on first principles that can help address this knowledge gap.
-Identify who/what/where so that we may follow up where appropriate.

What are the barriers to using this existing information?

E.g., difficult to access, requires highly technical skill set, not synthesized or digested for use in management decision-making

Additional research needs: What else do managers need in order to address the question?

Detail the following needs: data (one time sampling or continuous monitoring?), expertise/people, funding, and timing

Are there temporal considerations? *Does this require one-time sampling or continuous monitoring?*

Are there spatial considerations? *Is this research applicable to the Bay region as a whole, or are there particular areas/locations of the Bay to which this research may be most/least applicable?*

Anticipated results tied back to Management Question(s)

How can managers use the resulting information – tie the results back to how it will answer the original management question.

How could the resulting information be shared effectively with managers?

Identify known or potential challenges

E.g., funding, timing, feasibility. Does this apply to one aspect of the research strategy or to the thing as a whole?

Potential phasing of the research

E.g., order of events, data to be collected, etc. – short, medium, long-term needs.

Appendix E

Research Strategy Groups – General Discussion Points

Fate and Transport

- Do we really want to direct all sediment from the watershed to marshes and baylands rather than the subtidal Bay?
- There are distinct sediment needs of people and infrastructure, in addition to those for biological services. Habitat goals could direct the question of "where" to assist with marsh accretion.
- Should the "how" and "where" components be addressed together, or in separate studies? Consensus was they should be addressed together.
- It is important to understand the dynamics of sediment moving around first, in order to be able to model it, and ultimately make design decisions regarding where sediment can be placed or reused.
- Is marsh accretion really governed by the current sea level rise? If we place more sediment than necessary, the marsh will not retain it, so how do we determine how much sediment to add?
    - The percent retained depends on existing marsh elevation.
- Accretion is highly variable across the surface of a marsh, and the way sediment moves up channels can be very different, so the design of where and how to place sediment to assist with accretion is critical.
- Have studies been done to look at core samples different distances away from channels after floods to measure levee sediment carried by floods and deposited onto marshes?
- Tides don't necessarily contribute to direct sediment deposition on marshes, but rather send sediment up into channels, which is then washed back out by floods.
- How much sediment gets deposited in channels and never makes it to the Bay?
- What is the shear stress needed to move bedload (gravel)?
- The fate of sediment onto a marsh requires understanding of the tidal-fluvial interface. However, this is the hardest component to study along with the variation with time and space, as it is has the least known, is the most complex, and the hardest location to study.
    - This could be a good place for long term monitoring
- High water levels on a marsh correspond with scouring events, so it is unclear if this is when there is high sediment deposition
- What can we learn from:
    - Petaluma marsh?
    - Alviso Slough?
- There is no cost-effective technique for measuring mudflat baseline or change.

- Fringe marsh areas should not be neglected.
- It could take 20 years to learn about sediment fluxes, so we need to think about what we can implement sooner.

Sediment Budget and Supply

- The Bay sediment budget is largely constrained by a lack of understanding at the Golden Gate – outer coast interface
    - Potential studies upcoming Winter of 2015
- A sensitivity analysis of all parameters might be worthwhile to determine the smartest research investment looking into the future
- Would historical analyses help inform management decisions today or not?
- Is it possible to create "Plug and Play" dynamic simulation model, for use by sediment managers to extract a desired local budget given certain temporal and spatial constraints?
    - Answer: Theoretically, yes, but need actual numbers for everything, and would have to be dynamic when dealing with boundaries since there is not a simple algebraic solution.
- Regarding the phasing of research:
    - Could work on budgets for small areas with immediate management needs that will inform a larger budget over time
- Despite existing datasets from NOAA, OPC, and USGS, the data is challenging to use due to its uneven, cobbled-together nature.
- Beaches have formed along North Central Bay suggesting there could be a sand supply coming into Central Bay from the Golden Gate, feeding the Richmond area.
- Is there still a sand supply from the Sierra or is the Bay a mostly closed system with sand only coming from local tributaries and the outer coast?
- Is Ocean Beach←→Golden Gate an open or closed system?

Appendix F

Status, Risk, and Resilience Research Strategy Worksheet I– Marsh Shorelines

Management question(s) being addressed

- *Are there particular shoreline areas that are most at risk from sea level rise and erosion? (Filled out worksheet assuming the shoreline is **marsh).***

Research Question(s)

The question should identify the underlying knowledge gap in Bay Area science/understanding related to physical sediment processes that can directly address the above Management Questions.

- *How much sediment is needed, where and how frequently, to increase the resiliency of the wetlands to sea level rise?*

What do we already know?

-Existing data, projects, resources, or understanding based on first principles that can help address this knowledge gap.
-Identify who/what/where so that we may follow up where appropriate.

- *Present wetland elevation in relation to tidal range (elevation capital) – e.g. USGS studies in the North Bay by Karen Thorne and John Takekawa*
- *Present accretion rates measured by SET – John Callaway (USF), Matt Ferner (SF Bay NERR)*
- *Organic productivity - USGS studies in the North Bay by Karen Thorne and John Takekawa*
- *Suspended sediment concentration – USGS surveys by Dave Schoellhamer*
- *Future sedimentation rates – modeling with MARSH98 (Matt Brennan, ESA), WARMER (Karen Thorne, USGS), MEM (Lisa Schile, Smithsonian Environmental Research Center)*

What are the barriers to using this existing information?

E.g., difficult to access, requires highly technical skill set, not synthesized or digested for use in management decision-making

- *Models require calibration for specific marshes or subregions of the Bay*
- *Spatial and temporal estimates of suspended sediment concentration, salinity, etc.*
- *Estimates of accretion from sedimentation rates.*

Additional research needs: What else do managers need in order to address the question?

Detail the following needs: data (one time sampling or continuous monitoring?), expertise/people, funding, and timing

- *Calibration data (accretion rates etc.) is scarce.*
- *Variation of accretion rates with salinity is poorly understood.*
- *Consolidation processes are poorly understood.*
- *Trapping efficiency of marsh vegetation is poorly understood*
- *Retention of sediment on marsh following deposition is poorly understood*
- *Measurement of marsh scarp erosion rates*
- *Measurement of marsh transgression rates*

Are there temporal considerations? *Does this require one-time sampling or continuous monitoring?*

- *Temporal variation in processes needs to be studied*
- *Seasonal variations unknown*
- *Role of wave events, floods and extreme events needs to be understood*

Are there spatial considerations? *Is this research applicable to the Bay region as a whole, or are there particular areas/locations of the Bay to which this research may be most/least applicable?*

- *Spatial variation in processes is not understood – most monitoring and modeling is point based.*
- *Suspended sediments, wave energy and salinity vary around the Bay*

Anticipated results tied back to Management Question(s)

How can managers use the resulting information – tie the results back to how it will answer the original management question.

2009 pp. 1–25.

- *Creation of maps of erosion, elevation capital and transgression to show resilience of marshes.*
- *Identify risk to individual marshes*
- *Identify possible management actions to reduce risk*
- *Prioritize marshes to maximize effect of management actions.*

How could the resulting information be shared effectively with managers?

- *Creation of maps of erosion, elevation capital and transgression to show resilience of marshes. Perhaps hosted on a website, updated on a regular basis. Tied to regular monitoring of accretion rates*

Identify known or potential challenges

E.g., funding, timing, feasibility. Does this apply to one aspect of the research strategy or to the thing as a whole?

- *Funding of a network of monitored marshes is lacking.*
- *Takes time (years) to establish long term accretion rates*

Potential phasing of the research

E.g., order of events, data to be collected, etc. – short, medium, long-term needs.

- *Develop protocols for measurement of erosion, accretion and transgression (build on NERR Sentinel Site protocols)*
- *Set up SET and SSC network around Bay*

Status, Risk, and Resilience Research Strategy Worksheet II– Beach Shorelines

Management question(s) being addressed

Identify the priority management question(s) from Day 1 of the workshop being addressed by this strategy. Include origin "sector" (watershed, marsh/mudflat, other shoreline, bay/subtidal).

- *Are there particular shoreline areas that are most at risk from sea level rise and erosion? (Filled out worksheet assuming the shoreline is a **beach).***

Research Question(s)

The question should identify the underlying knowledge gap in Bay Area science/understanding related to physical sediment processes that can directly address the above Management Questions.

- *Where and what type of estuarine beaches are most appropriate in the Bay?*
- *How much coarse grain sediment is needed, of what texture, where and how frequently, to create estuarine beaches and increase the resiliency of space-limited shorelines to sea level rise?*

What do we already know?

-Existing data, projects, resources, or understanding based on first principles that can help address this knowledge gap.
-Identify who/what/where so that we may follow up where appropriate.

- *Example pilot projects*
  - *Aramburu Island*
  - *Crown Beach*
- *International research*
  - *Who?*
  - *Where?*
- *Location of sandy beaches*
  - *BCDC*
  - *SFEI*
- *Lateral transport?*
- *Beach ecology – Jenny Dugan UCSB*
- *Bayland Goals Update 2015 – Identification/prioritization of beach restoration sites?*

What are the barriers to using this existing information?

E.g., difficult to access, requires highly technical skill set, not synthesized or digested for use in management decision-making

- *There is a lack of location-specific information – most work comes from Europe*

Additional research needs: What else do managers need in order to address the question?

Detail the following needs: data (one time sampling or continuous monitoring?), expertise/people, funding, and timing

- *Pilot studies in the Bay are scarce.*
- *Stabilization of beaches is poorly understood.*
- *Alongshore transport processes are poorly understood.*
- *Wave energy and dynamics*
- *Ability of beaches to attenuate wave energy in space-limited locations i.e. along I-80*
- *Retention of sand on beach following nourishment/enhancement is poorly understood*
- *Measurement of beach erosion rates*

Are there temporal considerations? *I.e., one-time sampling or continuous monitoring?*

- *Temporal variation in processes needs to be studied*
- *Seasonal variations (winter vs. summer) unknown*
- *Role of wave events, floods and extreme events needs to be understood*

Are there spatial considerations? *Is this research applicable to the Bay region as a whole, or are there particular areas/locations of the Bay to which this research may be most/least applicable?*

- *Would likely work best between natural headlands or established pocket beaches*
- *May be ideal for space limited locations where there are not marshes, such as in Central Bay along I-80, where there is not room for wetlands to attenuate waves over large areas*
- *Wave energy and salinity vary around the Bay*

Anticipated results tied back to Management Question(s)

How can managers use the resulting information – tie the results back to how it will answer the original management question.

- *Creation of maps of quantified beach erosion*
- *Identify risk to individual shorelines*
- *Identify possible management actions to reduce risk*
- *Prioritize shorelines to maximize effect of management actions.*

How could the resulting information be shared effectively with managers?

- *Creation of maps of measured erosion, hosted on a website, updated on a regular basis. Tied to regular monitoring of beach stability*

Identify known or potential challenges

E.g., funding, timing, feasibility. Does this apply to one aspect of the research strategy or to the thing as a whole?

- *Very little local research of beaches in SF Bay to use as examples*

Potential phasing of the research

E.g., order of events, data to be collected, etc. – short, medium, long-term needs.

- *Develop protocols for measurement and monitoring of beach erosion rates and quantities seasonally, and on a regular basis*
  - *Can establish a beach in a year (short term)*